Using mineral equilibria to estimate $H_2O$ activities in peridotites from the Western Gneiss Region of Norway

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ABSTRACT

The Earth’s mantle is an important reservoir of $H_2O$, and even a small amount of $H_2O$ has a significant influence on the physical properties of mantle rocks. Estimating the amount of $H_2O$ in rocks from the Earth’s mantle would, therefore, provide some insights into the physical properties of this volumetrically dominant portion of the Earth. The goal of this study is to use mineral equilibria to determine the activities of $H_2O$ ($a_{H_2O}$) in orogenic mantle peridotites from the Western Gneiss Region of Norway. An amphibole dehydration reaction yielded values of $a_{H_2O}$ ranging from 0.1 to 0.4 for these samples. Values of $f_{O_2}$ of approximately 1 to 2 log units below the FMQ oxygen buffer were estimated from a $f_{CO_2}$-buffering reaction between olivine, orthopyroxene, and spinel for these same samples. These results demonstrate that the presence of amphibole in the mantle does not require elevated values of $a_{H_2O}$ (i.e., $a_{H_2O} = 1$) nor relatively oxidizing values of $f_{O_2}$ (i.e., >FMQ).

It is possible to estimate a minimum value of $a_{H_2O}$ by characterizing fluid speciation in C-O-H system for a given value of oxygen fugacity ($f_{O_2}$). Our results show that the estimates of $a_{H_2O}$ obtained from the amphibole dehydration equilibrium are significantly lower than values of $a_{H_2O}$ estimated from this combination of $f_{O_2}$ and C-O-H calculations. This suggests that fluid pressure ($P_{fluid}$) is less than lithostatic pressure ($P_{lith}$) and, for metamorphic rocks, implies the absence of a free fluid phase.

Fluid absent condition could be generated by amphibole growth during exhumation. If small amounts of $H_2O$ were added to these rocks, the formation of amphibole could yield low values of $a_{H_2O}$ by consuming all available $H_2O$. On the other hand, if the nominally anhydrous minerals (NAMs) contained significant $H_2O$ at conditions outside of the stability field of amphibole they might have served as a reservoir of $H_2O$. In this case, NAMs could supply the OH necessary for amphibole growth once retrograde $P$-$T$ conditions were consistent with amphibole stability. Thus, amphibole growth may effectively dehydrate coexisting NAMs and enhance the strength of rocks as long as the NAMs controlled the rheology of the rock.

Keywords: Amphibole equilibria, C-O-H fluid equilibria, $H$ solubility, nominally anhydrous minerals, mantle fluid, peridotite

INTRODUCTION

Peridotites are the dominant rock type in the Earth’s upper mantle and are a common constituent of orogenic zones. $H_2O$ has a significant influence on the physical properties of peridotites. For example, small amounts of $H_2O$ can have relatively profound effects on the melting relations of mantle peridotites (Kushiro 1972; Nicholls and Ringwood 1972, 1973; Green 1973, 2015; Nehru and Wyllie 1975; Hauri et al. 2006; Green et al. 2014). $H_2O$ also enhances ionic diffusion rate, thereby reducing the effective viscosity of minerals such as olivine (Hirth and Kohlstedt 1996; Karato and Jung 1998; Mei and Kohlstedt 2000a, 2000b). Given that modeling convection in the mantle requires constraints on viscosity of mantle peridotites (Solomatov 1995; Moresi and Solomatov 1998; Tackley 1998), estimates of mantle $H_2O$ content are required to model convection and determine the threshold amount of $H_2O$ for the operation of plate tectonic style of convection (Moresi and Solomatov 1998). Furthermore, the development of deformation microstructures in olivine may be related to it is OH content (Jung and Karato 2001; Jung et al. 2006; Ohuchi et al. 2012), and, therefore, the interpretation of mantle seismic anisotropy may depend, to some extent, on the OH content of olivine (Nakajima and Hasegawa 2004; Long and van der Hilst 2005; Mainprice et al. 2005; Ohuchi et al. 2012).

Clearly, determining the OH contents of the minerals in mantle peridotites will provide insight into various mantle properties and processes. Direct determination of the $H_2O$ content of the mantle relies on the analysis of mantle peridotites, and these samples may be xenoliths or orogenic peridotites (i.e., masses of peridotite, presumably of mantle origin, that have been emplaced in the crust). The $H_2O$ content of the minerals in mantle peridotites has been characterized by determining the amount of $H$ contained in nominally anhydrous minerals (NAMs), such as olivine, pyroxene, and garnet. This characterization of mantle NAM OH content has largely been confined to xenoliths (Ingrin and Skogby 2000; Bell et al. 2003; Maldener et al. 2003; Peslier...